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INTRODUCTION TO SEPTEMBER 1986 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the fourteenth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the first quarter of calendar year 1986.

Organization of Bulletin: This issue contains abstracts for all Center papers released for publication by NBS in the quarter and citations and abstracts for Center papers published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication". Papers published in the quarter appear under the subheading "Recently Published". Following each abstract is the telephone number of the individual to contact for more information on the topic; unless otherwise noted, this person is the first author. This issue also includes an announcement of recently issued standard reference materials and a list of sponsors of the work.

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Note on Publication Lists: Bibliographies covering both recent and earlier work are available from each division. The current issue of each is identified under the "Publication Lists" in the "Additional Information" section.

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SEMICONDUCTOR TECHNOLOGY

Silicon Materials

Released for Publication

Gladden, W. K., and Baghdadi, A., **Free Carrier Absorption and Interstitial Oxygen Measurements.**

The infrared (IR) absorption of both n- and p-type silicon samples were measured over the concentration range ~10^{15} cm^{-3} to 10^{17} cm^{-3}. The free carrier absorption exhibited a power-law dependence with wavenumber. The data were fit to a logarithmic function with this dependence, and these results were applied to the determination of the baseline from which to compute the corrected net IR absorption at 1107 cm^{-1} due to interstitial oxygen. Application of this correction for the free carrier absorption results in an improvement of 3% to 30% in the accuracy of the oxygen content determination at concentrations above 10^{16} atoms/cm^3.
[Contact: (301) 921-3786]

Recently Published

Baghdadi, A., **Measurement of the Oxygen and Carbon Content of Silicon Wafers by Fourier Transform Spectrophotometry,** Inorganic Materials Characterization, L.A. Casper, Ed., ACS Symposium Series 295, pp. 208-229 (American Chemical Society, 1986).

Fourier transform infrared (FT-IR) spectrophotometry is a rapid, nondestructive characterization technique which is being increasingly applied on a large scale to the routine measurement of the oxygen and carbon content of silicon wafers used for the fabrication of microelectronic devices. Control of the oxygen content is needed to achieve acceptable yields in modern device processing, particularly for those processes which utilize oxide precipitates to protect active regions of devices from contamination by metallic impurities during high-temperature processing. The interlaboratory reproducibility of the measurement is not adequate considering the degree of control of the oxygen that is required. This review focuses primarily on the measurement of oxygen and carbon in silicon and on methods for improving quantitative FT-IR absorption measurements on semiconductor wafers.
[Contact: (301) 921-3786]

Lowney, J.R., **Impurity Bands and Band Tailing in Moderately Doped Silicon,** J. Appl. Phys., Vol. 59, No. 6, pp. 2048-2053 (15 March 1986).

The density of states of the valence and conduction bands in silicon has been calculated at room temperature for dopant densities near the transition between the existence of a distinct impurity band and its coalescence with the continuum band to form a band tail. The dopant densities for the three cases considered are: 1) 1.5 × 10^{18} cm^{-3} acceptors; 2) 6.2 × 10^{18} cm^{-3} acceptors; and 3) 1.2 × 10^{19} cm^{-3} donors compensated by 6.2 × 10^{18} acceptors. The calculation is based on multiple-scattering theory with the self-energy calculated self-consistently to all orders of the interaction. The results show a small but significant amount of effective band-gap narrowing.
[Contact: (301) 921-3786]

Analysis Techniques

Released for Publication

Bullis, W.M., Watanabe, M., Baghdadi, A., Yue-zhen, L., Scace, R.I., Series, R.W., and Stallhofer, P., **Calibration of Infrared Absorption Measurements of Interstitial Oxygen Concentration in Silicon,** to be published in the Proceedings of the Silicon Symposium, Boston, Massachusetts, May 1986.

Many calibration factors for infrared absorption measurements of oxygen in silicon have been reported in the literature and adopted as standard during the past three decades. Reasons for this

Analysis Techniques, cont'd.

variability are examined and a new international experiment to establish a universally acceptable value and the reliability to which it can be found are described.
[Contact: Aslan Baghdadi (301) 921-3786]

Ehrstein, J. R., **Spreading Resistance Measurements - An Overview.**

Spreading resistance is the most versatile electrical technique for characterizing depth profiles in silicon. However, it is being increasingly challenged as an analytical method by shrinking device geometries. Consequently, refinement of such aspects as probe conditioning, sample preparation and bevel angle measurement is needed, and traditional practice regarding calibration, algorithms, and profile interpretation must be reexamined. Based on examples drawn from the author's work, multilaboratory experiments, and recent literature to illustrate and discuss these topics, this paper will attempt to summarize the current status of the measurement and its interpretation showing both strong points and apparent limitations.
[Contact: (301) 921-3786]

Dimensional Metrology

Released for Publication

Nyyssonen, D., **Linewidth Calibration for Bright-Chromium Photomasks,** to be published as NBSIR 86-3357.

Linewidth measurement errors are introduced when an anti-reflective (AR) chromium photomask standard such as NBS Standard Reference Materials 474 and 475 is used to calibrate an optical linewidth measurement system for subsequent measurements on another material such as bright chromium whose optical properties (index of refraction, thickness, reflectance, and edge geometry) do not match those of the calibration standard. In addition to differences in the optical properties of the materials, the magnitude of these errors varies from system to system and depends upon resolution, choice of edge-detection criterion, the presence of flare light in the optical system, and detector response. These errors are greatest when measurements are made in reflected light due to the greater sensitivity to the mismatch in optical parameters of the materials between the calibration standard (AR-chromium) and the material to be measured (bright chromium). This report, therefore, recommends use of transmitted light for linewidth measurements on photomasks and as close a match as possible between the material parameters of the calibration standard and those of the part being measured in order to ensure a realistic assessment of the accuracy and precision of subsequent measurements.
[Contact: (301) 921-3625]

Recently Published

Nyyssonen, D., **Procedure for Calibration of Ferrite Gaps in Magnetic Tape Heads Traceable to NBS AR-Chromium Optical Linewidth SRMs,** NBSIR 86-3306 (January 1986).

Accurate calibration of micrometer and submicrometer optical linewidth measuring systems requires that the calibration standard match the properties of the line to be measured. The NBS photomask linewidth standards have been designed for use by the integrated circuit community and are not directly suitable for use in other applications. A method of calibrating systems for measuring the width of ferrite gaps in magnetic calibrating systems for measuring the width of ferrite gaps in magnetic tape heads has been developed that involves a two-step calibration using the NBS anti-reflecting-chromium photomask as the primary reference standard. This primary standard is used in transmitted green light to calibrate the linewidths on a secondary black-chromium photomask. This is a valid procedure

Dimensional Metrology, cont'd.

because these lines are patterned in black-chromium layers that are thin compared to the wavelength of the green light and have negligible transmission. Since this secondary black-chromium photomask has similar optical properties to ferrite gaps when viewed in reflected green light, it can then be used to calibrate the linewidth measuring system to be used for ferrite gaps. The results of a preliminary study of this method shows that the errors associated with this two-step process are below 0.1 μm. The study also indicated that without this two-step process, the errors could be 0.3 μm or more.
[Contact: Robert D. Larrabee (301) 921-3625]

Integrated Circuit Test Structures

Recently Published

Ellenwood, C.H., and Mattis, R.L., **Release Notes for STAT2 Version 2.00A: An Addendum to NBS Special Publication 400-75**, NBSIR 85-3292 (January 1986).

STAT2 is a FORTRAN program which is used to analyze and display data from microelectronic test structures fabricated on semiconductor wafers. The program reads data as a two-dimensional array, extracts sample statistical values, identifies outliers, calculates replacement values for outliers, and makes histograms and circular gray-tone data maps. Version 2.00A is an adaptation of STAT2 to run under Version 3.2 of the RSX-11M operating system. This operating system is used on the automatic tester which acquires the test structure data. Data can therefore be taken and analyzed on the same system.
[Contact: (301) 921-3801]

Mattis, R.L., **Release Notes for STAT2 Version 1.7: An Addendum to NBS Special Publication 400-75**, NBSIR 86-3333 (March 1986).

This document describes the changes which have been made in the STAT2 computer program since its documentation in NBS Special Publication 400-75, Semiconductor Measurement Technology: A FORTRAN Program for Analysis of Data from Microelectronic Test Structures, and NBS Internal Report 83-2779, Release Notes for STAT2 Version 1.31. It is assumed that the reader has these documents, and no attempt is made to review STAT2 features or operation. The changes extend the functionality and versatility of the program. More specifically, the new features added in version 1.7 include data base extension, an input data format suitable for test sites not in a periodic array, an outlier exclusion algorithm suitable for small numbers of sites, common site exclusions for related data sets, a vector map, a scatter plot, a trend chart, extended macro command file capability, and other changes. Following the description of the changes is an annotated listing of new error messages. This document and the two previous publications cited constitute the documentation of version 1.7 of STAT2.
[Contact: (301) 921-3801]

O'Keeffe, T.W., Cresswell, M.W., Linholm, L.W., and Radack, D.J., **Evaluation and Improvement of E-Beam Exposure Routines by Use of Microelectronic Test Structures**, Extended Abstract Digest of the IEEE VLSI Workshop on Test Structures, Long Beach, California, February 17-18, 1986, pp. 182-194.

This paper describes the use of the cross-bridge test structure in conjunction with a series of interconnect test structures to assess and improve the exposure routines and procedures in the replication of submicron features. The interconnect test structures used in this experiment are resistors which include both serpentine and comb-like interconnect patterns and can be used to assess line continuity and line-to-line isolation. Results obtained during the evaluation of line continuity, resolu-

IC Test Structures, cont'd.

tion, linewidth, and proximity exposure effects are presented.
[Contact: Loren W. Linholm (301) 921-3801]

Radack, D.J., and Linholm, L.W., **The Application of Microelectronic Test Structures for Propagation Delay**, Extended Abstract Digest of the IEEE VLSI Workshop on Test Structures, Long Beach, California, February 17-18, 1986, pp. 191-207.

This paper presents a comparison of the ring oscillator, the inverter chain, and the delayed Johnson counter for measurement of the propagation delay of an inverter. It describes design considerations that will improve the precision and accuracy of the measurement. Modifications to the delayed Johnson counter which allow timing comparisons to be performed on-chip are also described.
[Contact: (301) 921-3801]

Roitman, P., Suehle, J.S., Russell, T.J., and Gaitan, M., On **the Measurement of Capacitance on Wafers**, Extended Abstract Digest of the IEEE VLSI Workshop on Test Structures, Long Beach, California, February 17-18, 1986, pp. 96-104.

Capacitance measurements of both capacitor and transistor structures can provide critical parameters for process monitoring, process modeling, device modeling, and circuit modeling. However, accurate measurements of capacitance on small devices located on large silicon wafers are very difficult. The problem is simply that very low-level analog measurements must be made at the end of a necessary system of cables and probes. Several authors have proposed building capacitance meters on the wafer, which would provide relatively high-level outputs to the external test system. A method has been chosen to improve the capability to measure capacitance on wafers directly. This improvement involved three parts of the experiment: the design of the capacitors, the design of the probe fixturing, and the instrumentation. These are discussed in turn.
[Contact: (301) 921-3625]

Schafft, H.A., Grant, T., Mandel, J., and Shott, J., **Report on an Interlaboratory Experiment**, Extended Abstract Digest of the IEEE VLSI Workshop on Test Structures, Long Beach, California, February 17-18, 1986, pp. 306-325.

An interlaboratory experiment involving 15 laboratories and associated experiments conducted at NBS are described and the results given. The twofold purpose of the experiments is 1) to assess the reproducibility of electromigration characterizations made with equivalent test structures by laboratories using their own test methods and 2) to broaden the technical base needed to develop electromigration guidelines. Specially designed test chips (NBS-42), from one metallization lot, were used in the experiments. The electromigration test structures provided to the participating laboratories are made of unpassivated, sputter-deposited Al 1%Si on oxidized Si.
[Contact: (301) 921-3801]

Schafft, H.A., and Saxena, A.N., **Electromigration Test Methodology and Characterization**, Proceedings of the Third IBM Electromigration Symposium, Poughkeepsie, New York, April 1-2, 1985, unpaged.

The accuracy of electromigration characterizations of metallizations may be affected significantly by the design of the electromigration test structure and by the conditions and procedures used in testing these structures. These effects are shown in a thermal analysis of a straight-line test structure and its packaging. The analysis uses a thermal model for an electromigration test structure from which equations are derived to calculate the temperature profile along the structure. It also

IC Test Structures, cont'd.

uses experimental evidence to validate the thermal model and the use of a series of thermal resistance and capacitance networks to model the heat flow from the metallization through the silicon chip, package, and heat sink, and on to the oven environment.
[Contact: (301) 921-3801]

Device Physics and Modeling

Released for Publication

Albers, J., **Monte Carlo Calculation of Primary Kinematic Knock-On in SIMS.**

Secondary Ion Mass Spectrometry (SIMS) occupies a central position in atomic profiling of semiconductor device structures. One of the possibilities for distortion of the profiles is the phenomenon of knock-on, in which the incident sputtering ion transfers enough kinetic energy to the impurity atoms to push them deeper into the material before they can be sputtered and counted. The effects of sputtering and primary kinematic knock-on are investigated by means of a Monte Carlo code previously used to study ion implantation processes. In particular, the dependence of the primary kinematic knock-on on the mass and energy of the sputtering ion as well as the mass of the impurity atom are presented.
[Contact: (301) 921-3621]

Bennett, H.S., **Device Physics for Modeling GaAs Bipolar Transistors**, to be published in the Proceedings of the Semiconductor Research Corporation Conference on Bipolar Technology, Tempe, Arizona, April 24-25, 1986.

The accuracy and reliability of predictions from numerical simulations of advanced bipolar transistors depend on model input parameters. These parameters include the variations with doping and carrier concentrations in both n-type and p-type material of 1) the valence and conduction band edges, 2) the effective intrinsic carrier concentrations, 3) the minority carrier mobilities, and 4) the minority carrier lifetimes. This paper contains a summary of recent advances in device physics for modeling silicon bipolar transistors with submicrometer dimensions and high concentrations of dopant ions and carriers. It also contains preliminary results in device physics for modeling those regions of GaAs bipolar transistors which have high concentrations of either dopant ions or carriers. The latter results are based on lessons learned from modeling advanced silicon bipolar devices.
[Contact: (301) 921-3621]

Bennett, H. S., **High Dopant and Carrier Concentration Effects in Gallium Arsenide: Band Structure & Effective Intrinsic Carrier Concentrations.**

The quality and reliability of predictions from numerical simulations of GaAs/AlGaAs devices, such as heterojunction bipolar transistors, depend on input parameters. These parameters include the variations with doping and carrier concentrations of the valence and conduction band edges and of the effective intrinsic carrier concentrations for heavily doped p-type and n-type gallium arsenide. The Klauder self-energy method is used to calculate the effects of the one-body interactions among the dopant ions and the carriers in heavily doped gallium arsenide at 300 K. The many-body interactions of exchange and correlation are estimated by interpreting optical absorption measurements and by calculations based on degenerate theory. When densities exceed 10^{19} cm^{-3} in p-type and 10^{17} cm^{-3} in n-type GaAs, one-body and many-body terms become of the same order of magnitude and should be included in calculations of band structure changes and of properties which depend on the density of states, such as carrier transport and effective intrinsic carrier concentrations.
[Contact: (301) 921-3621]

Device Physics & Modeling, cont'd.

Bennett, H.S., **Modeling Silicon Emitters for VLSI Transistors**, to be published in the Proceedings of the Workshop on New Developments in the Physics of Homojunctions and Heterojunctions, Leuven, Belgium, May 28-29, 1986.

The accuracy and reliability of predictions from numerical simulations of advanced bipolar transistors for VLSI applications depend on model parameters. These parameters include the variations with doping and carrier concentrations in both n-type and p-type silicon of 1) the valence and conduction band edges, 2) the effective intrinsic carrier concentrations, 3) the minority carrier mobilities, and 4) the minority carrier lifetimes. This paper reviews recent advances in device physics for modeling the emitters of bipolar transistors with submicrometer dimensions and high concentrations of dopant ions and carriers.
[Contact: (301) 921-3621]

Other Semiconductor Metrology Topics

Released for Publication

Reeve, G.R., **Alternate EMI Measurement Techniques for Microelectronic Circuits.**

The purpose of this paper, which was originally presented as an unpublished talk at a seminar held in March 1985 at the National Bureau of Standards, Gaithersburg, Md., is to suggest some new possibilities in metrology for evaluating the effects of electromagnetic interference (EMI) on microelectronics and integrated circuits in particular.

There is some concern that the increasingly complex integrated circuits now appearing with larger chip areas and smaller device geometries (e.g., those designed for the Very-High-Speed Integrated Circuit (VHSIC) program or classed as very-large-scale integrated (VLSI) circuits) will individually prove more susceptible to the effects of EMI than earlier generations. This concern also extends to the performance of the new devices in instruments and other equipment. Existing techniques utilizing pin voltage upset measurements may not be sufficient to properly characterize the behavior of these integrated circuits (ICs) in the presence of EMI. Some possible adaptations of EMI measurement techniques presently in use or being developed at the National Bureau of Standards (NBS) and other laboratories are presented for consideration.
[Contact: (303) 497-3557]

Wunder, S.L., Bell, M.I., and Zerbi, G., **Band Broadening of CH_2 Vibrations in the Raman Spectra of Polymethylene Chains.**

The isotropic and anisotropic linewidths of methylene vibrations in a homologous series of alkanes of increasing chain length have been measured in the liquid state as a function of temperature. The bandwidths of the CH_2 symmetric stretching modes, which are in Fermi resonance with overtones of the CH_2 bending vibrations, are temperature insensitive over a 200-K interval, explained in terms of a vibrational dephasing mechanism (inhomogeneous broadening) for these modes. In contrast, for the bending and antisymmetric vibrations, significant band broadening occurs over this same temperature interval. In addition, for these modes, both the absolute value of the bandwidth and the relative rate of increase of the bandwidth with increasing temperature decrease with increasing chain length. These observations are consistent with a reorientational broadening mechanism as the principal bandwidth contribution for these vibrations. Hindered end-over-end rotation of the molecules, which contributes to the band broadening for very low molecular weight alkanes, rapidly becomes too slow to be observable on the time scale of the Raman experiment for

Other Semiconductor Topics, cont'd.

the higher molecular weight alkanes and polyethylene. For longer chain lengths, torsional backbone motions coupled to the high frequency antisymmetric stretching modes can account for the breadth of the bands.
[Contact: Michael I. Bell (301) 921-3786]

FAST SIGNAL ACQUISITION, PROCESSING, & TRANSMISSION

Waveform Metrology

Released for Publication

Adair, R.T., Ehret, R.L., and Livingston, E.M., **Measurement of RF Signal Generator Phase Noise Fluctuations Using a One Generator, Delay Line Method.**

A technique is described which utilizes a single generator and a delay line for the measurement of frequency domain phase fluctuations in synthesized signal generators. Terms are defined and equations developed for theory and calculations of phase noise in a 1-Hz bandwidth offset 20 kHz from signal frequencies which range from 0.45 to 2000 MHz. The function and contribution of each component in the measurement system are presented. Advantages of this method are discussed.
[Contact: (303) 497-3461]

Turgel, R.S., **NBS 50 kHz Phase Angle Calibration Standard,** to be published as NBS Technical Note 1220.

A detailed description is given of the features of an electrical phase angle calibration standard designed for operation over a frequency span of 2 Hz to 50 kHz. The phase resolution of this calibrator extends from just below 2 millidegrees at the low end of the frequency range to about 5 millidegrees at the high end. The uncertainty in the phase angle is a function of frequency, amplitude, and amplitude ratio of the two outputs. It varies from 5 to 50 millidegrees.
[Contact: (301) 921-2727]

Recently Published

Gans, W.L., **Calibration and Error Analysis of a Picosecond Pulse Waveform Measurement System at NBS,** Proceeding of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 86-90 (January 1986).

The primary system used at the National Bureau of Standards to measure fast (picosecond-nanosecond range), repetitive, electrical pulse parameters consists of a wide-band (dc-18 GHz) sampling oscilloscope interfaced to a minicomputer. This paper describes the major calibration and analysis techniques used to reduce the effects of errors inherent in this system, both deterministic and random in nature.
[Contact: (303) 497-3538]

Laug, O.B., Stenbakken, G.N., and Leedy, T.F., **Electrical Performance Tests for Audio Distortion Analyzers,** NBS Technical Note 1219 (January 1986).

Electrical performance test procedures for audio distortion analyzers were developed by the National Bureau of Standards for the U.S. Army Communications-Electronics Command. The report provides detailed, step-by-step test procedures that are based on specifications supplied by the Army for purposes of evaluating audio distortion analyzer bid samples. Examples of data sheets and tables are also provided for recording interim and final results.

The report discusses the philosophy of each measurement procedure with a view toward providing an understanding of the basic metrology required to perform the measurements. In addition, the sources of measurement error are discussed. The primary applications and basic principles of modern audio distortion analyzers are also presented.
[Contact: (301) 921-2727]

Waveform Metrology, cont'd.

Lawton, R.A., Riad, S.M., and Andrews, J.R., **Pulse and Time-Domain Measurements,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 77-81 (January 1986).

A review of the state-of-the-art and science of pulse parameter measurements is given including recent advances in the use of real-time oscilloscopes, waveform recorders, equivalent time sampling oscilloscopes, and counter-timers in the measurement of repetitive and single transient signals. Recent advances in the use of artifact waveform standards and modern signal analysis techniques to compensate for measurement distortion are highlighted. The formation and progress of an IEEE committee which is developing a performance standard for waveform recorders is also described.
[Contact: (303) 497-3339]

Cryoelectronic Metrology

Released for Publication

Barbanera, S., Lambert, N., and Zimmerman, J.E., **A Versatile Experimental Low-Power 4 K Cryocooler.**

The construction of a low-power cryocooler consisting of a five-stage plastic Stirling cooler with an additional Joule-Thomson stage is described. Among its novel features are a contamination-free pneumatic helium compressor and displacer drive. Valve timing is under computer control. Titanium foil embedded in the cylinder wall reduces helium diffusion through the plastic. The Joule-Thomson stage uses the same low-pressure helium as the Stirling stages. The Stirling system cools down below 9 K. The Joule-Thomson stage delivers 5-mW cooling at 4.2 K.
[Contact: Richard E. Harris (303) 497-3776 or -3988]

Crete, D.G., McGrath, W.R., Richards, P.L., and Lloyd, F.L., **Performance of Arrays of SIS Junctions in Heterodyne Mixers.**

We have made a systematic experimental study of the performance of millimeter-wave quasiparticle heterodyne mixers which use arrays of superconductor-insulator-superconductor (SIS) tunnel junctions. Sets of arrays with N = 1, 5, 10, 25, and 50 junctions in series were fabricated by photolithography. All of the arrays in a given set were made on a single wafer so that their response time parameters $\omega_S R_N C$ were the same (ω_S = signal frequency; R_N = junction normal-state resistance; c = junction capacitance). Junction areas were scaled so that the total impedance was the same for each array in a set. Sets of arrays from four wafers with values of $\omega_S R_N C$ ranging from 1.3 to 7 were evaluated in mixers at 36 GHz. These measurements showed that the signal power required to saturate the mixers varies as N^2, and the conversion efficiency is essentially independent of N for all values of $\omega_S R_N C$. The mixer noise temperature is independent of N for large values of $\omega_S R_N C$. Therefore, the dynamic range of an SIS quasiparticle mixer can increase in proportion to N^2. For small values of $\omega_S R_N C$, however, the mixer noise increases systematically with N. This correlation suggests that the junction capacitance affects the coupling between junctions that can contribute to the noise.
[Contact: Frances L. Lloyd (303) 497-3254]

Hamilton, C.A., Kautz, R.L., and Lloyd, F.L., **The NBS Josephson Array voltage Standard.**

It has been realized for many years that the accuracy of Josephson voltage standards can be substantially improved by using many junctions in series to generate a large voltage. A simple series extension of the single junction standard requires individual control of the bias current for each junction of 100 mV using 20 junctions. In 1977 Levinsen et

Cryoelectronic Metrology, cont'd.

al. suggested a method to avoid the multiple bias problem by using constant-voltage steps which cross the zero-current axis of the junction I-V curve. This allows a large array of junctions to share a common current bias at or near zero. With an array of 1000 or more junctions, a quantized voltage of 1 V is possible. After nearly ten years of effort, the problems of fabrication, stability, and radiofrequency distribution are largely solved and Josephson standards at the 1-V level are a reality. This paper reviews the design and operation of series array voltage standards and describes the efforts at NBS to engineer a versatile, reliable, and easily used voltage standard system.
[Contact: (303) 497-3740]

Recently Published

Hamilton, C.A., Kautz, R.L., and Lloyd, F.L., **A Josephson Series Array Voltage Standard at One Volt**, NCSL 1985 Workshop & Symposium, Boulder, Colorado, July 15-18, 1985, pp. 71-77.

Josephson voltage standards have long been limited by their low 1- to 10-mV output level. A new method for operating 1000 or more Josephson junctions in series has produced a practical standard at the 1-V level. The junction array is in the form of a microstrip which is finline coupled to a waveguide at one end and is terminated at the other end. The whole circuit is fabricated on a (6×12)-mm silicon substrate. With applied radiation at 72 GHz, the junction array produces up to 8000 quantized levels at the voltages nhf/2e. (In the U.S. 2e/h has an assigned value of 483593.420 GHz/V_{NBS}.) By selecting the level, n, and fine tuning the frequency, f, any voltage from 0.1 to 1.2 V can be obtained. The high output voltage eliminates the need for a voltage divider and greatly reduces errors due to thermal voltages. When fully evaluated, the new standard is expected to have a precision of a few parts per billion.
[Contact: (303) 497-3740]

Hamilton, C.A., Kautz, R.L., Lloyd, F.L., and Steiner, R.L., **A Practical Josephson Voltage Standard at 1 V**, IEEE Electron Device Letters, Vol. EDL-6, No. 12, pp. 623-625 (December 1985).

A series array of 1484 pairs of Josephson junctions biased by microwaves at 72 GHz is demonstrated to provide stable quantized voltages at the 1-V level. The niobium/lead-alloy junctions used in the array are not affected by thermal cycling.
[Contact: (303) 497-3740]

Kautz, R.L., and Macfarlane, J.C., **Onset of Chaos in the rf-Biased Josephson Junction**, Physical Review A, Vol. 33, No. 1, pp. 498-509 (January 1986).

The onset of chaos in the radiofrequency-biased (rf-biased) Josephson junction is studied through numerical simulations. It is shown that the chaotic region predicted by the method of Melnikov spans only a narrow region of rf amplitudes and consists of weakly chaotic solutions which maintain phase lock with the rf bias. The experimentally observed threshold of chaos is shown to coincide with the onset of unlocked chaotic behavior at higher rf amplitudes.
[Contact: (303) 497-3991 or -3988]

Raisanen, A.V., McGrath, W.R., Richards, P.L., and Lloyd, F.L., **Broad-Band RF Match to a Millimeter-Wave SIS Quasi-Particle Mixer**, IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-33, No. 12, pp. 1495-1500 (December 1985).

An integrated superconducting microstrip is shown to be a convenient, flexible, and well-characterized matching element for a superconductor-insulator-superconductor (SIS) quasi-particle heterodyne mixer. The resonant interaction (Fiske modes) between the Josephson

Cryoelectronic Metrology, cont'd.

oscillations of a voltage-biased junction and the microstrip provides a convenient method for determining the electrical length of the microstrip line. An open-circuited microstrip stub that reflects a parallel inductance across the junction is used to broaden the bandwidth of the radiofrequency match of a 30- to 40-GHz SIS mixer. Measurements with Pb-alloy junctions in a full-height wavelength mixer with fixed mechanical tuning give an instantaneous bandwidth of 10 to 15 percent with a double sideband mixer noise temperature $T_M(DSB) = 10 \pm 2.5$ K.
[Contact: Frances L. Lloyd (303) 497-3254]

Antenna Metrology

Released for Publication

FitzGerrell, R.G., **Standard Linear Antennas, 30 MHz to 1000 MHz.**

Simple linear antennas are described that are designed to operate in the 30-MHz to 1000-MHz frequency range. Commercial coaxial hybrid junctions are used as balanced-to-unbalanced transmission line transformers (baluns) for the dipole antennas. The monopoles are fed unbalanced against a large ground screen. Calculated site attenuation (insertion loss) between pairs of these antennas over an assumed perfectly conducting ground plane is compared to insertion loss data measured using the 30-m by 60-m NBS ground screen. One-half of the mean value of the difference between the calculated and measured insertion loss data, expressed in decibels, is taken as a good estimate of individual antenna performance. For the antennas described here, this measure of performance is typically ≤ 0.05 dB, with a maximum possible value of ≤ 0.42 dB.
[Contact: (303) 497-3737]

Hill, D.A., and Koepke, G.H., **A Near-Field Array of Yagi-Uda Antennas for Electromagnetic Susceptibility Testing.**

In electromagnetic susceptibility testing of electronic equipment, the ideal incident field is a plane wave. To approximate this condition, a seven-element array of Yagi-Uda antennas has been constructed and tested at a frequency of 500 MHz. The element weightings are determined by a near-field synthesis technique which optimizes the uniformity of the field throughout a rectangular test volume in the near field of the array. The amplitude and phase of the electric field have been measured throughout the test volume with a short dipole probe, and the agreement with theory is excellent.
[Contact: (303) 497-3472]

Kanda, M., and Orr, R.D., **Near-Field Gain of a Horn and an Open-Ended Waveguide: Comparison Between Theory and Experiment.**

This paper gives the theory and supporting experimental measurements for the near-field gain of a rectangular pyramidal horn and an open-ended waveguide (OEG) at 450 MHz. The empirical near-field gain for the OEG is derived from experimental results obtained by a two-antenna method at about 2 GHZ. The theoretical near-field gain for the rectangular pyramidal horn is derived from Schelkunoff's formula. Two independent near-field gain measurements of these antennas are made using a three-antenna method and a transfer-standard-probe method. The discrepancy between theoretical and experimental results is typically less than ±2 dB.
[Contact: (303) 497-5320]

Recently Published

Lewis, R.L., and Newell, A.C., **An Efficient and Accurate Method for Calculating and Representing Power Density in the Near-Zone of Microwave Antennas,** NBSIR 85-3036 (December 1985).

An algorithm is presented for calculating near-zone and Fresnel-region fields in front of microwave antennas

Antenna Metrology, cont'd.

from discrete numerical values of the radiated plane-wave spectrum (complex far-field pattern). That is, the near fields are calculated by numerically integrating the plane-wave spectrum representation of the field. The crux of the analysis consists of handling a numerical instability which arises from integrating discrete data. A criterion is developed for limiting the integration domain in order to exclude highly oscillatory regions of the integrand. In turn, this leads to restricting the applicable output range over which the field can be computed. With the numerical instability problem thus resolved, fast Fourier transform techniques are used to assure efficient numerical integration over a large (but restricted) output range. The results are conveniently presented as relative power-density contours in planes formed by the longitudinal coordinate axis and one transverse coordinate axis. The algorithm is capable of extremely high accuracy, which is demonstrated by comparing predicted and measured near-fields for two distinct antennas, along with a comparison against an exact theoretical model. In the case of circularly symmetric excitation models for electrically large antenna apertures, the predicted relative near-zone power-density contour plots turn out to be a function of only the relative aperture distribution. Nomographs for obtaining absolute near-zone power densities are presented for a few typical aperture-distribution functions.
[Contact: (303) 497-5196]

Muth, L.A., **Interelement Interactions in Phased Arrays: Theory, Methods of Data Analysis, and Theoretical Simulations**, NBS Technical Note 1091 (December 1985).

We review theoretically the effects of multiple reflections and mutual impedances in array environments and study possible methods of far-field pattern data analysis to recover interaction effects. We use theoretical expressions derived earlier to calculate in a two-element linear array the mutual-impedance matrix and effective excitations of elements as functions of inter-element separation and n_{max}, the maximum mode number in the radiation pattern of the elements. Generalizations to two- and three-dimensional arrays are discussed.
[Contact: (303) 497-3603]

Newell, A.C., Stubenrauch, C.F., and Baird, R.C., **Calibration of Microwave Antenna Gain Standards**, Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 129-132 (January 1986).

Techniques for precision calibration of microwave antenna gain standards are described with discussions of applicability and associated uncertainties. Included are the three-antenna, extrapolation, swept-frequency, and near-field techniques.
[Contact: (303) 497-3743]

Yaghjian, A.D., and Wittmann, R.C., **The Receiving Antenna as a Linear Differential Operator: Application to Spherical Near-Field Scanning**, IEEE Transactions on Antennas and Propagation, Vol. AP-33, No. 11, pp. 1175-1185 (November 1985).

The general receiving antenna is represented as a linear differential operator converting the incident field and its spatial derivatives at a single point in space to an output voltage. The differential operator is specified explicitly in terms of the multipole coefficients of the antenna's complex receiving pattern. When the linear operator representation is applied to the special probes used in spherical near-field measurements, a probe-corrected spherical transmission formula is revealed that retains the form, applicability, and simplicity of the nonprobe-corrected equations. The new spherical transmission formula is shown to be consistent

Antenna Metrology, cont'd.

with the previous transmission formula derived from the rotational and translational addition theorems for spherical waves.
[Contact: Ronald C. Wittmann (303) 497-3326]

Noise Metrology

Recently Published

Wait, D.F., **The Impact of Automation on NBS Noise Temperature Measurements,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 117-120 (January 1986).

The accuracy of calibrating a thermal noise source using the National bureau of Standards' automated radiometer and cryogenic primary noise standards is typically ±2 percent, compared with ±3 percent for corresponding services that used manual radiometers and hot primary standards. Using the automated radiometer, a noise source can typically be calibrated at three frequencies in the time a manual radiometer requires to calibrate one. The automated radiometer contains a six-port reflectometer, and noise sources with reflection coefficients as great as 0.3 can be tolerated without significantly affecting the calibration accuracy. This makes it practical to use a single broad-band, coaxial noise standard from 0.03 to 14 GHz. The six-port reflectometer also makes it possible to calibrate sources with connectors different from those of the primary standard with almost no additional degradation in accuracy.
[Contact: (303) 497-3610]

Microwave Metrology

Released for Publication

Adair, R.T., Reeve, G.R., and Gatterer, L.E., **Millimeter Wave Standards: An Emerging Need.**

Several technology surveys concerning millimeter-wave measurement needs and capabilities have been conducted by the National Bureau of Standards (Electromagnetic Fields Division) and others. The results of some of these studies are summarized. Current millimeter wave standards and calibration capabilities at the National Bureau of Standards are reviewed. The lack of national standards in certain frequency bands may lead to problems with specification, acceptance testing, and calibration of some components and systems.
[Contact: (303) 497-3461]

Daywitt, W.C., **A Simple Technique for Determining Joint Losses on a Coaxial Line from Swept-Frequency Reflection Data.**

A need to separate connector loss from swept-frequency automatic network analyzer measurements to check an attenuation calculation for a low-loss, coaxial line has led to a simple graphical technique for determining the connector loss. It is also possible to determine joint losses around center conductor bead supports on the line itself. Preliminary results indicate that losses in the milli-decibel range can be determined to a precision of a few tenths of a milli-decibel or better, even though the data are obscured by considerable connector loss and calibration error. Results were checked by independent measurements and show excellent agreement.
[Contact: (303) 497-3720]

Ginley, R.A., Allred, C.M., and Chamberlin, G.C., **1.25 MHz Attenuation Measurement System.**

A system has been developed to make highly accurate measurements of 6-dB nominal increments of attenuation at 1.25 MHz. Initial experiments indicate a typical systematic error of 0.00005 dB (5 μB) with a resolution of 0.00001 dB (1 μB). A special Linearity Measurement System using NBS-constructed, linear-tuned hybrids and power detectors has

Microwave Metrology, cont'd.

been used to determine the nonlinearity of a tuned 1.25-MHz power detector. This detector utilizes a single thermistor bead design with thermal isolation to obtain nearly linear tracking of a 4:1 change in input power. The nonlinear correction for this change, determined by the Linearity Measurement System, is on the order of 13 μB for the detector presently in use. This calibrated detector and another of similar design are used in the Attenuation Measurement System to make power ratio measurements to determine the change in attenuation of the device under test. It is anticipated that nominal 6-dB changes can be measured with initial insertion loss of up to 100 dB with an accuracy of 0.001 dB. Devices submitted to NBS for measurement require special design considerations in order to keep mismatch errors from significantly degrading the estimated accuracies given above.
[Contact: (303) 497-3634]

Hoer, C.A., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Treatment of Systematic Errors.**

Expressions are derived for calculating systematic errors in dual six-port or four-port measurements of reflection coefficient and scattering parameters, as a result of imperfections in the transmission line standard used to calibrate the system. A new mathematical model for a four-port reflectometer is described which makes it easier to visualize and analyze these errors.
[Contact: (303) 497-3705]

Recently Published

Hoer, C.A., **Multiple Network Analyzers**, McGraw-Hill Yearbook of Science and Technology, pp. 289-292 (1986).

This section discusses the theoretical basis and operational considerations for multiport network analyzers, which are linear passive microwave networks used to measure complex reflection coefficient and power. Methods for measuring these quantities at a fixed frequency have long been known and use, for instance, bridge or slotted-line techniques. In recent years very wide-band systems (covering perhaps a 10:1 range of frequency) have been developed. To make measurements on such systems one frequency at a time by manual methods is prohibitively time-consuming. Automatic network analyzers, using wide-band tunable sources and receivers under computer control, have been developed, enabling measurements to be made more rapidly. They are, however, complex and expensive, and more recently the use of multiport couplers has resulted in simpler systems.
[Contact: (303) 497-3705]

Hoer, C.A., **Summary of the NBS Calibration Services and Systems**, Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 32-35 (January 1986).

This paper gives a brief summary of the calibration services available at the National Bureau of Standards for attenuation, phase shift, impedance, power, and voltage at radiofrequency and microwave frequencies.
[Contact: (303) 497-3705]

Judish, R.M., **Quality Control of Measurements - Measurement Assurance**, Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 23-25 (January 1986).

The ability to relate individual measurements to nationally accepted standards is a requirement of traceability. This paper discusses a perspective in which the goals of traceability are viewed in terms of performance requirements on measurement quality as reflected in a statement of uncertainty.
[Contact: (303) 497-3380]

Microwave Metrology, cont'd.

Kamper, R.A., **Uncertainty Charts for RF and Microwave Measurements,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 27-32 (January 1986).

The scope of the calibration services for electrical quantities in the range of frequency from 0 to 100 GHz that are available from the National Bureau of Standards is discussed briefly in a historical context. Some plans for improved services that will be available in the near future are noted. Charts showing the variation of uncertainty with magnitude over the full range of the respective calibration services are presented.
[Contact: (303) 497-3535]

Reeve, G.R., and Miller, C.K.S., **Current NBS Metrology Capabilities and Limitations at Millimeter Wave Frequencies,** Precision Measurements Association Newsnotes (9681 Business Center Drive, Rancho Cucamonga, CA 91730), Vol. II, pp. 55-67 (1985).

The National Bureau of Standards (NBS) establishes national artifact standards and provides a metrology base for U.S. industry and technology. NBS has not established all of the required metrology in the millimeter-wave frequency range to meet the needs of industry or government for this technology. This paper describes the technical demands of responding to the metrological challenges posed by millimeter-wave technology. A description of current capabilities at NBS is given for those parameters and frequencies where measurement services exist. The physical basis for selected novel standards, such as the 94-GHz thermal noise standard, is described to illustrate the changes required from lower frequency designs and the challenges that had to be overcome. Limitations in services and in concepts of standards for providing these services are described to indicate the degree of research that must be undertaken to satisfy future industrial needs in this evolving technology.
[Contact: (303) 497-3557]

Sladek, N.J., and Jesch, R.L., **Standardization of Coaxial Connectors in the IEC,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 14-18 (January 1986).

This paper reviews the requirements and standardization of coaxial connectors in the United States. It details the standardization of coaxial connectors within the International Electrotechnical Commission (IEC) Subcommittee SC46D "Connectors for RF Cables." A list of published IEC connector standards and a list of IEC standards under consideration are included.
[Contact: Robert L. Jesch (303) 497-3496]

Weidman, M., **Finline Diode Six-Port: Fundamentals and Design Information,** NBS Technical Note 1090 (December 1985).

The preliminary design and testing of a planar circuit six-port having diode detectors is described. The planar circuit medium was chosen to be finline, and all preliminary work was done in WR-42 waveguide (18 to 26.5 GHz). The finline substrate was alumina, and initially commercial beam-lead diodes were bonded to the finline metallization. The goal is to design an integrated circuit which could be fabricated on one chip (with diode detectors) and used as part of a six-port network analyzer in the waveguide bands above 18 GHz. Initial designs proved to be unsatisfactory because of high losses and reflections. Most of the problems have been solved, and a usable integrated finline circuit is a good possibility for a millimeter wave six-port.
[Contact: (303) 497-3210]

Laser Metrology

Recently Published

Case, W.E., and Sanders, A.A., **Laser Power and Energy Measurements and the NBS Laser Measurement Assurance Program (MAP)**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 281-285.

This paper describes the national standards for laser power and energy measurements maintained by the National Bureau of Standards and how the measurement services based on these standards are disseminated. Particular emphasis is devoted to the procedures and instrumentation used in these measurements. The Laser Measurement Assurance Program (MAP) is discussed in detail. The paper also presents a detailed procedure for the user to choose proper instrumentation and procedures to implement a measurements program in the laboratory.
[Contact: Aaron A. Sanders (303) 497-5341]

Johnson, E.G., Jr., **Direct Measurement of the Electric Field of a Laser Pulse-Theory**, NBS Technical Note 1084 (August 1985).

We consider realizing an electric field measuring apparatus by using optical processing, tapered optical fibers, and a pair of detectors at the end of each optical fiber. Using an appropriate computer-generated optical filter, we show it is possible to discriminate among a set of orthonormal modes used to represent the spatial features of the electric field with a signal-to-noise ratio of at least 100 to 1. If the positioning accuracies for various parts of the apparatus are properly set up, it is expected that the signal-to-noise ratio could be about 1000. The purpose of the tapered and graded-index fibers is to select the fundamental propagating mode in a fiber and to attenuate the other modes. The existence of these fibers allows the precise determination of the strength of each of the orthonormal modes being used as the spatial basis of the electric field before the optical processing. The detectors then measure the strength of each fundamental mode. There are 36 such modes for the apparatus under discussion--six for the x-dimension and six for the y-dimension. Propagation of the laser pulse is assumed to be along the z-axis. We use two detectors for each mode so that the polarization is determined.

This paper presents the conflicts in the design and gives a solution. The complete evaluation requires assembly of the proposed apparatus to assess final accuracy.
[Contact: (303) 497-3234]

Rasmussen, A.L., and Sanders, A.A., **Documentation of the NBS APD and PIN Calibration Systems for Measuring Peak Power and Energy of Low-Level 1.064 μm Laser Pulses**, NBSIR 85-3032 (December 1985).

National Bureau of Standards APD (avalanche) and PIN silicon photodiode transfer standards are documented for a calibration service to measure 1.064-μm laser pulses from $\sim 10^{-8}$ to $\sim 10^{-4}$ W peak power and $\sim 10^{-16}$ to $\sim 10^{-11}$ J energy. A modulated cw (continuous-wave) measurement system generating known low-level pulses is described. Calibration support equipment, systematic and random errors, and computer programs and calibration data are also described.
[Contact: (303) 497-5367 or -3616]

Rasmussen, A.L., and Sanders, A.A., **Transfer Standards for Energy and Peak Power of Low-Level 1.064 Micrometer Laser Pulses and Continuous Wave Laser Power**, Optical Engineering, Vol. 25, No. 2, pp. 277-285, (February 1986).

For the first time, traceable transfer standards have been developed for measuring 1.064-μm laser pulses with duration of about 10 to 100 ns, peak power density of about 10^{-8} to 10^{-4} W/cm^2, and energy density of about 10^{-16} to 10^{-11}

Laser Metrology, cont'd.

J/cm^2. These power and energy transfer standards use avalanche (APD) and PIN silicon photodiode detectors, respectively. They are stable and have total uncertainties of about 10%. The system for calibrating them and other devices consists of a cw (continuous-wave) Nd:YAG laser beam acousto-optically modulated to provide low-level laser pulses of known peak power and energy. With pulse height analyzer readout, the PIN transfer standard system records each pulse, from which the mean pulse energy and laser stability may be evaluated. With integrating voltmeter readout, this system can measure energy or average power. These pulsed and cw measurement techniques can be extended to the visible and other near-infrared wavelengths.
[Contact: (303) 497-5367 or -3616]

Simpson, P.A. and Sanders, A.A., **Pulse Considerations for Low-Level Laser Receivers**, to be published in the Proceedings of the Measurement Science Conference, Irvine, California, January 22-24, 1986.

Laser target designators and rangefinders use low-level receivers to detect the light reflected from the target. Present testing procedures for the receivers often use the measurement of the total energy of a light pulse which is generated with a pulsed LED (light-emitting diode). These procedures can be subject to significant error unless certain precautions are observed. Two new fast detectors of pulse shape with high sensitivity and extended wavelength range are described. These detectors can be used with low-level transfer standards for next generation laser target designator and rangefinder systems.
[Contact: (303) 497-3789]

Optical Fiber Metrology

Released for Publication

Danielson, B.L., Day, G.W., Franzen, D.L., Gallawa, R.L., Kim, E.M., Phelan, R.J., and Young, M., **Measurement Procedures for Optical Fiber and Related Components**, to be published as NBSIR 86-3042.

This report was prepared to provide guidance to those charged with establishing a facility for the testing of components for optical communications systems. Primary emphasis is on systems and procedures for optical fiber parameters--attenuation, bandwidth/distortion, core dimensions, index profile, and numerical aperture. Procedures for the testing of fiber components are discussed with emphasis on the use of optical time-domain reflectometry. Procedures for determining the radiant power and spectral characteristics of detectors are also included. A final topic is procedures for establishing the reliability of optical sources.
[Contact: (303) 497-5620]

Day, G.W., Vesser, L.R., Chandler, G.I., and Cernosek, R.W., **Progress in the Design of Optical Fiber Sensors for the Measurement of Pulsed Electric Currents.**

The state of the art in the design of fiber sensors for pulsed electric currents is reviewed. Some of the more useful configurations are described and compared. Transfer functions are computed and used to illustrate the effect of linear birefringence and twisting on the characteristics of the sensors. The technique of annealing bend-induced birefringence is described and its present capabilities indicated. An analysis of the ultimate limits to noise equivalent current is given, indicating that several orders of magnitude improvement should be obtainable.
[Contact: (303) 497-5204]

Recently Published

Danielson, B.L., **Optical Time-Domain Reflectometer Specifications and Per-**

Optical Fiber Metrology, cont'd.

formance Testing, Appl. Optics, Vol. 24, No. 15, pp. 2313-2322 (August 1, 1985).

From a researcher's as well as a user's point of view, it is highly desirable to adopt a common basis for specifying optical time-domain reflectometer performance parameters. This paper proposes some procedures and test methods which permit these devices to be characterized in a consistent way. Passive test fixtures are also described which may facilitate measurements of dynamic range and other reflectometer properties (the reflectometers addressed in this paper are used to characterize optical fibers and fiber installations).
[Contact: (303) 497-5620]

Day, G.W., McFadden, J.D.O., Veeser, L.R., Chandler, G.I., and Cernosek, R.W., **Optical Fiber Sensors for the Measurement of Pulsed Electric Currents**, NATO AGARD Conference, Guided Optical Structures in the Military Environment, Istanbul, Turkey, Sept. 23-27, 1985, Preprint 383, pp. 8-1 to 8-9.

Recent progress in the design of fiber sensors for pulsed electric currents is reviewed. Several of the most useful sensor configurations are described and compared. Models are used to predict the transfer function of these sensors, their sensitivity to non-ideal fiber properties, particularly linear birefringence, and methods for overcoming these problems. Other recent research is examined to suggest the prospect for sensors with improved sensitivity and stability.
[Contact: (303) 497-5204]

Franzen, D.L., **Determining the Effective Cutoff Wavelength of Single-Mode Fibers: An Interlaboratory Comparison**, Journal of Lightwave Technology, Vol. LT-3, No. 1, pp. 128-134 (February 1985).

The National Bureau of Standards, in cooperation with the Electronic Industries Association, conducted an interlaboratory measurement comparison among six fiber manufacturers to determine the effective cutoff wavelength of single-mode fibers. Measurement techniques based on transmitted power were used to determine cutoff wavelength on four fibers designed for single-mode operation at 1300 nm. NBS also contributed results using a spectral near-field technique. One-standard-deviation measurement spreads for the various techniques range from 6 to 12 nm. With the appropriate data analysis, single-bend attenuation and power-step methods give the same results. Both techniques are easily implemented as extensions to the usual spectral attenuation measurement.
[Contact: (303) 497-3346]

Franzen, D.L., **An Interlaboratory Measurement Comparison Among Fiber Manufacturers to Determine the Effective Cut-Off Wavelength and Mode Field Diameter of a Single Mode Fiber,** Technical Digest of the Conference on Optical Fiber Communication and the 3rd International Conference on Optical Fiber Sensors, San Diego, California, February 11-14, 1985, p. 36.

An interlaboratory measurement comparison to determine an effective cutoff wavelength and mode field diameter of a single-mode fiber was conducted by the National Bureau of Standards in cooperation with the Electronic Industries Association (EIA). Participants included NBS, several U.S. manufacturers, and some foreign laboratories. The purpose of the comparisons was to gather information on interlaboratory agreement when the same measurement techniques are used and to determine offsets between different techniques. The various procedures tested (three transmission methods for determining cut-off wavelength and four methods [transverse offset, near-field, far-field, and variable aperture far-field] for determining mode

Optical Fiber Metrology, cont'd.

field diameter) are currently pending before the EIA and represent current practice for manufacturers. Interlaboratory agreement and systematic offsets between methods are discussed.
[Contact: (303) 497-3346 or -5342]

Franzen, D.L., and Day, G.W., **Fiber Optics Emphasis on Single Mode - Conference Report,** NBS Journal of Research, Vol. 9, No. 1, p. 49 (January-February 1985).

The third biennial Symposium on Optical Fiber Measurements, sponsored by NBS in cooperation with the IEEE Optical Waveguide Communications Committee and the Optical Society of America, drew some 300 attendees to Boulder October 2-3, 1984 to hear 25 contributed papers, several invited papers, and to attend two workshops on the general subject of optical fiber measurements. This short note identifies several highlights of the Symposium.
[Contact: (303) 497-3346 or -5342]

Franzen, D.L., and Srivastava, R., **Determining the Mode-Field Diameter of Single-Mode Optical Fiber: An Interlaboratory Comparison,** Journal of Lightwave Technology, Vol. LT-3, No. 5, pp. 1073-1077 (October 1985).

The National Bureau of Standards, in cooperation with the Electronic Industries Association, conducted an interlaboratory measurement comparison among fiber manufacturers. Evaluated were transverse splice offset, near-field, far-field, and variable aperture far-field methods for determining mode-field diameter. Measurements were performed on five single-mode fibers at both 1300- and 1550-nm wavelengths. At 1300 nm, agreement was fairly good with the average one standard deviation being 0.15 μm for mode-field diameters in the 8- to 11-μm range. Distinct systematic differences among various techniques were observed at 1550 nm where mode distributions are not as Gaussian.
[Contact: (303) 497-3346 or -5342]

Maisonneuve, J.M., Churoux, P., and Gallawa, R.L., **Use of Mode Transfer Matrices in L.A.N. Loss Evaluation,** Proc. SPIE - International Society of Optical Engineering (P.O. Box 10, Bellingham, WA 98227-0010), Vol. 559, pp. 182-185 (1985) [Conference, San Diego, California, August 19-23, 1985].

A method using Mode Transfer Matrices to characterize step-index fiber components and predict local area network (LAN) power budget is presented. The results show this method is well adapted to describing modal power distribution variations.
[Contact: Robert L. Gallawa (303) 497-3761]

Shao, Y., Alvarez, R., Weimer, C., and Gallawa, R.L., **Pulse Spectrum Analysis Method of Measuring Fiber Bandwidth,** Proc. SPIE - The International Society for Optical Engineering (P.O. Box 10, Bellingham, WA 98227-0010), Vol. 559, pp. 207-210 [Conference, San Diego, California, August 19-23, 1985].

A system for measuring optical fiber bandwidth utilizing the pulse spectrum analysis method (PSA) has been established. This paper discusses problems inherent to that system such as signal-to-noise ratio and off-peak error. Included are the results of bandwidth measurements for telecommunication grade fibers. Finally, the PSA method is compared to other bandwidth measurement methods.
[Contact: Robert L. Gallawa (303) 497-3761]

Shao, Y., and Gallawa, R.L., **Some Issues in Optical Fiber Bandwidth Measurements,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 228.

The measurement of optical fiber bandwidth, using methods in common use in the fiber community, is discussed along with difficulties and variabilities encountered.
[Contact: Robert L. Gallawa (303) 497-3761]

Other Fast Signal Topics

Released for Publication

Young, M., **Low-Cost LCD Video Display for Optical Processing.**

A liquid gate and a low-pass filter are needed to use a new liquid-crystal display video monitor effectively in a coherent-processing system. The results of some simple spatial-filtering experiments are demonstrated.
[Contact: (303) 497-3223 or -5342]

Recently Published

Judish, R.M., **Quality Control of Measurements - Measurement Assurance,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 23-25 (January 1986).

The ability to relate individual measurements to nationally accepted standards is a requirement of traceability. This paper discusses a perspective in which the goals of traceability are viewed in terms of performance requirements on measurement quality as reflected in a statement of uncertainty.
[Contact: (303) 497-3380]

Kamper, R.A., **Uncertainty Charts for RF and Microwave Measurements,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 27-32 (January 1986).

The scope of the calibration services for electrical quantities in the range of frequency from 0 to 100 GHz that are available from the National Bureau of Standards is discussed briefly in a historical context. Some plans for improved services available in the near future are noted. Charts showing the variation of uncertainty with magnitude over the full range of the respective calibration services are presented.
[Contact: (303) 497-3535]

Ku, H.H., and Judish, R.M., **Fundamentals of Error Analysis,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 25-27 (January 1986).

This paper discusses the process of assessing the uncertainty of measurement results through error analysis. We restrict the discussion to sources of errors, measurement errors, modeling errors, and calibration errors in the context of physical experiments.
[Contact: Robert M. Judish (303) 497-3496]

Sladek, N.J., and Jesch, R.L., **Standardization of Coaxial Connectors in the IEC,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 14-18 (January 1986).

This paper reviews the requirements and standardization of coaxial connectors in the United States. It details the standardization of coaxial connectors within the International Electrotechnical Commission (IEC) Subcommittee SC46D "Connectors for RF Cables." A list of published IEC connector standards and a list of IEC standards under consideration are included.
[Contact: Robert L. Jesch (303) 497-3496]

Erratum

The wrong abstract appeared in the June 1986 issue of the Technical Progress Bulletin [NBSIR 86-3344-2] for the following published paper. The correct abstract follows the citation.

Young, M., **The Scratch Standard is Only a Cosmetic Standard,** Laser Focus/Electro-Optics, pp. 138-140 (November 1985). [An identical paper appeared in the Proceedings of the Conference on Laser Induced Damage in Optical Materials, Boulder, Colorado, October 28-30, 1985.]

In this paper, I present a history of the scratch and dig standard and show

Other Fast Signal Topics, cont'd.

that this standard has since its inception been recognized as a cosmetic standard and not as an objective or performance standard. In addition, I attempt to dispel the myth that the scratch standard was changed during the 1960s and show that scratch number cannot be related to scratch width. Finally, I describe a preliminary experiment that suggests that the scratch standards have not aged with time and are, in fact, extremely stable.
[Contact: (303) 497-3223 or -5342]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Kelley, E.F., Hebner, R.E., Anderson, W.E., Lechner, J.A., and Blue, J.L., **The Effect of an Oil-Paper Interface Parallel to an Electric Field on the Breakdown Voltage at Elevated Temperatures.**

This paper reports the measurements made in a study of the electrical breakdown location in the vicinity of an oil-paper interface over the temperature range from room temperature to 150°C. The data indicated that the electrical breakdown occurred at the interface from 15% to 43% of the time, depending on the details of the particular set of measurements. A theoretical analysis shows that this experimental result is consistent with the electric field enhancement, the area over which the enhancement occurs, and the spread in the breakdown voltages for nominally identical tests.
[Contact: (301) 921-3121]

Misakian, M., McKnight, R.H., and Fenimore, C., **Calibration of Aspirator-Type Ion Counters and Measurement of Unipolar Charge Densities**, to be published as NBS Technical Note 1223.

The characterization of a parallel-plate apparatus which can produce a unipolar ion density that is suitable for calibrating aspirator-type ion counters operating in the ground plane is described. The influence of a dc electric field, air motion, Coulomb repulsion, and diffusion on the transport of ions into the ion counter are examined to determine their effects on instrument calibration and measurements in the vicinity of high-voltage dc transmission lines. An ion density which is known with an uncertainty of less than ±9% is used to check the performance of an ion counter with and without a duct at its entrance. Results of laboratory measurements of ion density under a monopolar high voltage line, which complement the studies with the parallel-plate apparatus, are also described.
[Contact: (301) 921-3121]

Siddagangappa, M.C., Van Brunt, R.J., and Phelps, A.V., **Influence of Oxygen on the Decomposition Rate of SF_6 in Corona.**

The absolute charge rates-of-production of discharge-generated gaseous by-products SOF_4, SOF_2, SO_2F_2, SO_2, and CO_2 have been measured in compressed SF_6/O_2 mixtures at a constant pressure. The normalized total rate of oxyfluorides plus SO_2 production per SF_6 mole does not increase significantly with the addition of O_2 up to 50% in SF_6 and increases slowly for $[O_2]>50\%$. The formation of SO_2 in all SF_6/O_2 mixtures was insignificant. Instead, the deposition of sulfur (S^- ions) on the anode increased with O_2 concentration. The yield of CO_2 from oxidation of carbon on the electrode was also observed to increase, with O_2 content. Probable mechanisms for the formation of SOF_2, SO_2F_2, SOF_4, S^- ions, and CO_2 are discussed. The measured by-product yield as a function of percent O_2 is compared with the calculated maximum rate of SF_6 decomposition induced by electron collision in the discharge. The theoretical model used to calculate the rate of

Power Systems Metrology, cont'd.

SF_6 decomposition in SF_6/O_2 mixtures is briefly discussed. As observed for SF_6/N_2 and SF_6/Ne mixtures, the primary effect of O_2 on SF_6 decomposition appears to be the inhibition of the recombination of SF_6 dissociation products due to dilution.
[Contact: Richard J. Van Brunt (301) 921-3121]

Recently Published

FitzPatrick, G.J., Forster, E.O., Kelley, E.F., and Hebner, R.E., **Streamer Initiation in Liquid Hydrocarbons**, 1985 Annual Report, IEEE Conference on Electrical Insulation and Dielectric Phenomena, Amherst, New York, Oct. 20-24, 1985, pp. 27-32.

Using 93X magnification and a framing rate of 2×10^7 frames/s, the initiation of prebreakdown streamers in toluene, isooctane, and a white oil has been photographed. The initial growth from a negative point electrode was a thin pencil-like structure, having a growth rate of 2 to 3×10^4 cm/s, which subsequently branched into a tree-like structure. Positive streamers were found to develop into a more filamentary structure than negative streamers. Under nominally identical conditions, a positive streamer may grow, then disappear; may grow to bridge the gap; or may grow to a certain length, then persist.
Contact: Robert E. Hebner (301) 921-3121]

Fulcomer, P.M., **NBS Ambient Magnetic Field Meter for Measurement and Analysis of Low-Level Power Frequency Magnetic Fields in Air**, NBSIR 86-3330 (December 1985).

This report describes a portable, battery-powered magnetic fieldmeter which has been developed to provide improved accuracy in the measurement and analysis of low-level and ambient power-frequency magnetic fields. Accurate measurement of such fields is becoming increasingly important as public concern grows over the possibility that exposure to such fields may produce effects on human health. Included in the report are a description of the instrumentation, a circuit analysis, a discussion of the calibration procedures together with an uncertainty analysis, and some sample measurement results. The instrumentation enables measurement of power-frequency magnetic field in air with an overall uncertainty of less than one percent over a range from 50 nanotesla (500 microgauss) to 200 microtesla (2 gauss) and an overall uncertainty of less than two percent down to 2 nanotesla (20 microgauss). It also enables the percentage of each harmonic present in the field to be determined to an uncertainty of less than three percent.
[Contact: (301) 921-3121]

Hebner, R.E., **Research for Electric Energy Systems -- An Annual Report**, NBSIR 86-3316 (March 1986).

This report documents the technical progress in the five investigations which make up the project "Support of Research Projects for Electrical Energy Systems," Department of Energy Task Order Number 137, funded by the U.S. Department of Energy's Office of Energy Systems Research and performed in the Electrosystems Division of the U.S. National Bureau of Standards.
[Contact: (301) 921-3121]

Kamper, R.A., **Uncertainty Charts for RF and Microwave Measurements**, Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 27-32 (January 1986).

The scope of the calibration services for electrical quantities in the range of frequency from 0 to 100 GHz that are available from the National Bureau of Standards is discussed briefly in a historical context. Some plans for improved services that will be available in the near future are noted. Charts showing the variation of uncertainty

Power Systems Metrology, cont'd.

with magnitude over the full range of the respective calibration services are presented.
[Contact: (303) 497-3535]

Pulse Power Metrology

Released for Publication

Day, G.W., Vesser, L.R., Chandler, G.I., and Cernosek, R.W., **Progress in the Design of Optical Fiber Sensors for the Measurement of Pulsed Electric Currents.**

The state of the art in the design of fiber sensors for pulsed electric currents is reviewed. Some of the more useful configurations are described and compared. Transfer functions are computed and used to illustrate the effect of linear birefringence and twisting on the characteristics of the sensors. The technique of annealing bend-induced birefringence is described and its present capabilities indicated. An analysis of the ultimate limits to noise equivalent current is given, indicating that several orders of magnitude improvement should be obtainable.
[Contact: (303) 497-5204]

Recently Published

Day, G.W., McFadden, J.D.O., Veeser, L.R., Chandler, G.I., and Cernosek, R.W., **Optical Fiber Sensors for the Measurement of Pulsed Electric Currents**, NATO AGARD Conference, Guided Optical Structures in the Military Environment, Istanbul, Turkey, Sept. 23-27, 1985, Preprint 383, pp. 8-1 to 8-9.

Recent progress in the design of fiber sensors for pulsed electric currents is reviewed. Several of the most useful sensor configurations are described and compared. Models are used to predict the transfer function of these sensors, their sensitivity to non-ideal fiber properties, particularly linear birefringence, and methods for overcoming these problems. Other recent research is examined to suggest the prospect for sensors with improved sensitivity and stability.
[Contact: (303) 497-5204]

Magnetic Materials and Measurements

Released for Publication

Cromar, M.W., Clark, A.F., and Fickett, F.R., **Flux Limit of Cosmic-Ray Magnetic Monopoles From a Multiply Discriminating Superconductive Detector.**

A multiply discriminating, three-loop superconducting monopole detector was operated for one year. During this period, 8523 hours of data were accumulated. The sensing area averaged over solid angle for trajectories passing through a loop was 178 cm^2. Including double coincidence events from trajectories passing through the shield but not through a loop, the total sensing area averaged over solid angle was 1195 cm^2. No candidate monopole events were observed leading to an upper limit on the flux of cosmic ray magnetic monopoles of 5.0×10^{-12} cm^{-2} sr^{-1} s^{-1} with a 90% confidence level.
[Contact: (303) 497-5375]

Recently Published

Fulcomer, P.M., **NBS Ambient Magnetic Field Meter for Measurement and Analysis of Low-Level Power Frequency Magnetic Fields in Air**, NBSIR 86-3330 (December 1985).

This report describes a portable, battery-powered magnetic fieldmeter which has been developed to provide improved accuracy in the measurement and analysis of low-level and ambient power-frequency magnetic fields. Accurate measurement of such fields is becoming increasingly important as public concern grows over the possibility that exposure to such fields may produce effects on human health. Included in the report

Magnetic Materials, cont'd.

are a description of the instrumentation, a circuit analysis, a discussion of the calibration procedures together with an uncertainty analysis, and some sample measurement results. The instrumentation enables measurement of power-frequency magnetic field in air with an overall uncertainty of less than one percent over a range from 50 nanotesla (500 microgauss) to 200 microtesla (2 gauss) and an overall uncertainty of less than two percent down to 2 nanotesla (20 microgauss). It also enables the percentage of each harmonic present in the field to be determined to an uncertainty of less than three percent.
[Contact: (301) 921-3121]

Goldfarb, R.B., Rao, K.V., and Chen, H.S., **New Magnetic Phase Diagram of the Amorphous Pd-Fe-Si Ferroglass Alloy System**, Journal of Magnetism and Magnetic Materials, Vol. 54-57, pp. 111-112 (1986).

The magnetic phase diagram of amorphous $Pd_{80-x}Fe_xSi_{20}$ is examined for values of x between 5 and 22. We use the peak in the imaginary component of ac susceptibility to determine the ferromagnetic-like to spin-glass transition temperatures T_{fg}. It is found that the T_{fg} curve is strongly field dependent and increases monotonically with increasing Fe concentration, even around x = 22.
[Contact: (303) 497-3650]

Superconductors

Released for Publication

Clark, A.F., Heinz, W., Rizzuto, C., Fast, R.W., and Klippling, G., **Conference Report on the Tenth International Cryogenic Engineering Conference**, Cryogenics.

The Tenth International Cryogenic Engineering Conference was held in Otaniemi, Finland, 31 July to 3 August 1984, hosted by the Helsinki University of Technology. More than 300 attendees representing 22 countries contributed 220 papers on such diverse subjects as sensing human brainwaves from their magnetic fields to superconducting magnets the size of railroad cars and to ultralow-temperature refrigerators which can achieve nuclear temperatures of the order of nanokelvin. The special topic for this conference was cryogenics in medicine, and thus many of the plenary talks covered cryosurgery, magnetic resonance imaging, SQUID magnetometers for heart and brain waves, and biological preservation.
[Contact: (303) 497-3253]

Ekin, J.W., Moreland, J., and Brauch, J.C., **Electromechanical Properties of Superconductors for DOE Fusion Applications**, to be published as NBSIR 86-3044.

This is an interim report presenting data on superconductor performance under mechanical load, data needed for the selection of superconductors and the mechanical design of superconducting magnets for DOE fusion energy systems. A further aim of the reported research is to measure and understand the electromechanical properties of promising new superconductor materials with strong application potential at high magnetic fields. Results include the following. The first studies of strain vs. critical-current were made on a Chevrel-phase superconductor, $PbMo_6S_8$. Chevrel-phase superconductors were found to have a large strain effect, comparable in magnitude to that in A-15 superconductors like Nb_3Sn. Electromechanical-property measurements of an experimental liquid-tin-infiltrated Nb_3Sn conductor showed it to have an irreversible strain limit twice as large as that of bronze-process superconductors and a significantly higher overall critical-current density; the liquid-infiltration process thus has the potential for development of a practical Nb_3Sn conductor with both superior critical-current density and extremely good mechanical properties. Electromechanical parameters were obtained on

Superconductors, cont'd.

several Nb_3Sn conductors that are candidate materials for superconducting fusion magnets, including conductors fabricated by the bronze, internal-tin, and jelly-roll processes. Thermal contraction data are reported on several new structural materials for superconductor sheathing and reinforcement, and a new diagnostic tool for probing the energy gap of practical superconductors has been developed using electron tunneling.
[Contact: (303) 497-5448]

Recently Published

Fickett, F.R., **Investigation of a Practical Superconductor with a Copper Matrix, Annual Report and Final Summary of Project 255**, International Copper Research Association (708 Third Avenue, New York, NY 10017) (1985).

In this report we summarize the work performed on four INCRA projects covering a span of about six years. The main goal of the work was to investigate the in-situ superconductors, those produced by the relatively rapid cooling of a melt containing essentially non-miscible components. The component with the higher melting point precipitates out as small particles during the cooling. Subsequent drawing of the resulting boule results in fine filaments of this material (the superconductor) in the lower-melting matrix (usually oxygen-free copper or a copper-tin alloy).
[Contact: (303) 497-3785]

Goodrich, L.F., Minervini, J.V., Clark, A.F., Fickett, F.R., Ekin, J.W., and Pittman, E.S., **Development of Standards for Superconductors - Interim Report**, NBSIR 85-3027 (January 1985).

A cooperative program with the Department of Energy, the National Bureau of Standards, and private industry is in progress to develop standard measurement practices for use in large-scale applications of superconductivity. The goal is the adoption of voluntary standards for the critical parameters and other characterizations of practical superconductors. Progress for the period January 1982 through December 1983 is reported. The major effort was the procurement, selection, and certification of the first superconducting wire for critical current measurements as a Standard Reference Material (SRM 1457). Other work reported here includes effect of geometry on current transfer, lap-joint resistance, and ac losses.
[Contact: (303) 497-3143]

ELECTROMAGNETIC INTERFERENCE

Released for Publication

Crawford, M.L., and Koepke, G.G., **Performing EM Susceptibility/Vulnerability Measurements Using a Reverberation Chamber.**

This paper discusses the design, evaluation, and use of a reverberation chamber for performing electromagnetic susceptibility (EMS) measurements of electronic equipment. Included are brief descriptions of the test procedures, application advantages and limitation, some EMS test results, interpretation of test results relative to free-space test methods, and an estimate of measurement uncertainty.
[Contact: (303) 497-5497]

Friday, D.S., and Adams, J.W., **A Statistical Characterization of Electroexplosive Devices (EED) Relevant to Electromagnetic Compatibility (EMC) Assessment**, to be published as NBS Technical Note 1094.

Electroexplosive devices (EEDs) are electrically fired explosive initiators used in a a wide variety of applications. The nature of most of these applications requires that the devices function with near certainty when required and remain inactive otherwise. Recent concern with pulsed electromagnetic interference and nuclear

Electromagnetic Interference, cont'd.

electromagnetic pulse made apparent the lack of methodology for assessing EED vulnerability. A new and rigorous approach for characterizing EED firing levels is developed in the context of statistical linear models and is discussed in this paper. We combine statistical theory and methodology with thermodynamic modeling to determine the probability that an EED, of a particular type, fires when excited by a pulse of a given width and amplitude. The results are presented in a manner that can be applied to any type of EED for which the hot-wire explosive binder does not melt below the firing temperature. Included are methods for assessing model validity and for obtaining probability plots, called "Firing Likelihood Plots". A method of measuring the thermal time constant of an EED is given. Knowledge of this parameter is needed to evaluate the effect of a train of pulses. These statistical methods are both more generalized and more efficient than previous methods for EED evaluation. The results provide information which is crucial for considering the effects of currents induced by impulsive electromagnetic fields of short duration compared to the thermal time constant of the EED.
[Contact: (303) 497-5395]

Hill, D.A., and Koepke, G.H., **A Near-Field Array of Yagi-Uda Antennas for Electromagnetic Susceptibility Testing.**

In electromagnetic susceptibility testing of electronic equipment, the ideal incident field is a plane wave. To approximate this condition, a seven-element array of Yagi-Uda antennas has been constructed and tested at a frequency of 500 MHz. The element weightings are determined by a near-field synthesis technique which optimizes the uniformity of the field throughout a rectangular test volume in the near field of the array. The amplitude and phase of the electric field have been measured throughout the test volume with a short dipole probe, and the agreement with theory is excellent.
[Contact: (303) 497-3472]

Kanda, M., and Driver, L.D., **A Broadband, Electric-Field Probe Using Resistively Tapered Dipoles, 100 kHz - 18 GHz**, to be published in the 1986 IEEE MTT-S International Microwave Digest. [A more extensive treatment of this development is to be given at the 1986 IEEE International Symposium on Electromagnetic Compatibility].

This paper discusses the theoretical, design, fabrication, evaluation, and calibration aspects of a prototype broadband electric-field probe. Its resistively tapered miniature dipole elements allow measurement of electric fields between 1 and 1600 V/m from 1 MHz to 15 GHz, with a flatness of ±2 dB and an isotropic response of ±0.3 dB.
[Contact: (303) 497-5320]

Kanda, M., and Orr, R.D., **Near-Field Gain of a Horn and an Open-Ended Waveguide: Comparison Between Theory and Experiment.**

This paper gives the theory and supporting experimental measurements for the near-field gain of a rectangular pyramidal horn and an open-ended waveguide (OEG) at 450 MHz. The empirical near-field gain for the OEG is derived from experimental results obtained by a two-antenna method at about 2 GHz. The theoretical near-field gain for the rectangular pyramidal horn is derived from Schelkunoff's formula. Two independent near-field gain measurements of these antennas are made using a three-antenna method and a transfer-standard-probe method. The discrepancy between theoretical and experimental results is typically less than ±2 dB.
[Contact: (303) 497-5320]

Kanda, M., and Orr, R.D., **Near-Zone Gain of a Horn and an Open-Ended Waveguide: Comparison Between Theory and Experiment.**

Electromagnetic Interference, cont'd.

This paper gives the theory and supporting experimental measurements for the near-zone gain of a rectangular pyramidal horn and an open-ended waveguide (OEG) at 450 MHz. The empirical near-zone gain for the OEG is derived from experimental results obtained by a two-antenna method at about 2 GHz. The theoretical near-zone gain for the rectangular pyramidal horn is derived from Schelkunoff's formula. Two independent near-zone gain measurements of these antennas are made using a three-antenna method and a transfer-standard-probe method. The discrepancy between theoretical and experimental results is typically less than ±1 dB.
[Contact: (303) 497-5320]

Reeve, G.R., **Alternate EMI Measurement Techniques for Microelectronic Circuits.**

The purpose of this paper, which was originally presented as an unpublished talk at a seminar held in March 1985 at the National Bureau of Standards, Gaithersburg, Md., is to suggest some new possibilities in metrology for evaluating the effects of electromagnetic interference (EMI) on microelectronics and integrated circuits in particular.

There is some concern that the increasingly complex integrated circuits now appearing with larger chip areas and smaller device geometries (e.g., those designed for the Very-High-Speed Integrated Circuit (VHSIC) program or classed as very-large-scale integrated (VLSI) circuits) will individually prove more susceptible to the effects of EMI than earlier generations. This concern also extends to the performance of the new devices in instruments and other equipment. Existing techniques utilizing pin voltage upset measurements may not be sufficient to properly characterize the behavior of these integrated circuits (ICs) in the presence of EMI. Some possible adaptations of EMI measurement techniques presently in use or being developed at the National Bureau of Standards (NBS) and other laboratories are presented for consideration.
[Contact: (303) 497-3557]

Recently Published

Adams, J.W., and Vanzura, E., **Shielding Effectiveness Measurements of Plastics**, NBSIR 85-3035 (January 1986).

Measurement of shielding effectiveness of plastic materials with respect to electromagnetic radiation poses serious problems due to the insulating nature of many plastics. A method of making these measurements using a flanged coaxial holder overcomes some of the difficulties.
[Contact: (303) 497-3328]

Kanda, M., Larsen, E.B., Borsero, M., Galliano, P.G., Yokoshima, I., and Nahman, N.S., **Standards for Electromagnetic Field Measurements,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 120-128 (January 1986).

This paper describes the methodology for standard electromagnetic field measurements using anechoic chambers, open sites, guided-wave structures, and probes as transfer standards.
[Contact: (303) 497-5320]

Larsen, E.B., **Calibration and Meaning of Antenna Factor and Gain for EMI Antennas,** Directory and Design Guide of the Control of EMI, Item 1986, pp. 114ff (1986) [Robar Industries, Inc., 20 Clipper Road, West Conshohocken, PA 19428-2721].

The National Bureau of Standards offers a calibration service for field strength meters and electromagnetic interference (EMI) antennas in the frequency range of 10 kHz to 10 GHz. The antennas most commonly used are loops for magnetic fields from 10 kHz to 50 MHz, monopoles

Electromagnetic Interference, cont'd.

for vertically polarized electric fields from 30 kHz to 300 MHz, and dipoles or related antennas for electric fields from 20 MHz to 10 GHZ. The majority of calibrations consist of determining the "antenna factor" (K) or "realized" gain (G_{re}), which permits the use of a 50-Ω receiver (tunable radiofrequency voltmeter) with the calibrated antenna to make measurements of radiated emissions. A receiver with attached antenna can also be calibrated as a system to measure the field strength directly.

There are three common independent techniques for calibrating an antenna to make field strength measurements. These are: (a) standard antenna method, (b) standard field method, and (c) insertion loss method. All three techniques lead to a calibrated gain or antenna factor - which are related to each other in a reciprocal fashion. In practice, however, the gain of an antenna is most commonly measured by comparing its output in a locally generated field to that of a "standard" receiving antenna, whose gain is accurately known. This approach is called a "relative" gain measurement. If the gain is determined without using another antenna having known gain, the procedure is called an "absolute" gain measurement. The three techniques for determining absolute gain and antenna factor are described.
[Contact: (303) 497-3540]

Ma, M.T., Kanda, M., Crawford, M.L., and Larsen, E.B., **Measuring Electromagnetic Interference, Part I: Open-Field Sites and TEM Cells**, Test and Measurement World, pp. 72ff (February 1986) [condensation of a portion of **A Review of Electromagnetic Compatibility/Interference Measurement Methodologies**, Proceedings of the IEEE, Vol. 73, No. 3, pp. 388-411 (March 1985)].

Measuring radiated electromagnetic power is essential to demonstrate conformance to various electromagnetic interference/compatibility (EMI/EMC) regulations and specifications. A number of methods are available -- open-field sites, transverse electromagnetic (TEM) cells, reverberating chambers, and anechoic chambers. Selection of a suitable technique requires a knowledge of the strengths and limitations of each. Proper interpretation of measured results then requires an intimate knowledge of the characteristics of the chosen site or facility.

Following a general introduction to the subject of testing for EMI/EMC, this first article in a three-part series discusses 1) measurements and problems using open-field sites and 2) measurements on small electrical equipment and devices in TEM cells for radiated susceptibility and radiated emission testing.
[Contact: (303) 497-3800]

Ma, M.T., and Koepke, G.H., **Measurements of Unintentional Electromagnetic Emissions,** Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 110-111 (January 1986).

A summary of a new method for determining the radiation characteristics of leakage from electronic equipment or other unintentional radiators of interference is presented. The theoretical background and specific measurement procedures for the method using a transverse electromagnetic cell are outlined. The theory and measurements have been verified in referenced work by the results of a simulated theoretical example and an experiment using a spherical dipole radiator. A reference is also given for mathematical analysis of the uncertainties in the final, extracted results when the experimental data are degraded by the background noise and measurement imperfections.
[Contact: (303) 497-3800]

Phelan, R.J., Jr., Larson, D.R., and Simpson, P.A., **A Sensitive, High**

Electromagnetic Interference, cont'd.

Frequency Electromagnetic Field Probe Using a Semiconductor Laser in a Small Loop Antenna, Proc. SPIE - International Society of Optical Engineering (P.O. Box 10, Bellingham, WA 98227-0010), Vol. 566, pp. 300-306 (1985) [Conference, San Diego, California, August 20-23, 1985].

Using a loop antenna in series with a semiconductor laser, an optically coupled electromagnetic field probe has demonstrated sensitivities better than 3 $\mu V/(m \cdot Hz^{1/2})$. The outside dimensions of the probe are equal to 5.7 × 5.7 × 1.3 cm^3. It can be used to measure fields with frequencies as high as 2 GHz. The dynamic range is estimated to exceed 6 orders of magnitude for incident microwave powers.
[Contact: (303) 497-3696 or -5342]

Randa, J., and Kanda, M., **Directional Scanning of Complex Electromagnetic Environments**, IEEE Transactions on Antennas and Propagation, Vol. AP-33, No. 12, pp. 1413-1416 (December 1985) [a shortened version of this paper appeared in the Proceedings of the 1985 International Symposium on Antennas and Propagation, Kyoto, Japan, August 20-22, 1985, pp. 899-902].

As radiofrequency and microwave sources (both intentional and inadvertent) multiply, the electromagnetic (EM) environment in which electronic devices (and people) must function becomes increasingly complicated, while at the same time its characterization becomes more important. In order to completely characterize an EM environment without knowledge of the radiating sources, the sampling theorem requires that systematic measurements of the amplitude and phase of the field be made throughout the volume at spacings of no more than one-half wavelength of the highest frequency present. Implementing this number of measurements is often impossible and seldom convenient. There is a need for practical techniques which would determine useful properties of an EM environment from relatively few measurements. One recent suggestion for such a technique is to use directional measurements at a single point in conjunction with a plane-wave expansion of the field. This paper reports the formulation of the technique and the results of a simulation using it.
[Contact: (303) 497-3150]

Wilson, P.F., Adams, J.W., and Ma, M.T., **Measurement of the Electromagnetic Shielding Capabilities of Materials**, Proceedings of the IEEE, Special Issue on Radio Measurement Methods and Standards, Vol. 74, No. 1, pp. 112-115 (January 1986).

Electromagnetic shielding is typically measured in terms of insertion loss, that is, the reduction in the fields coupled between a transmitter and a receiver which results from interposing the shield material. Although the insertion loss concept is simply stated, questions arise when one attempts to interpret specific insertion loss measurements. Insertion loss data depend not only on the inherent shielding effectiveness of the material, but also on the antenna types used for the measurement, the incident field distribution, the sample size, a possible contact impedance between the test material and its mount, and other factors. For a given sample of shield material, varying these factors can lead to a large range of possible measured insertion loss values. Both the above considerations and existing shielding effectiveness measurement systems are discussed briefly in this paper. The emphasis is on potential difficulties encountered in making even relative comparisons of results and on the importance of understanding how the measurement system used affects the data.
[Contact: (303) 497-3842]

ADDITIONAL INFORMATION

Lists of Publications

Gibson, K.A., Page, J.M., and Miller, C.K.S., **A Bibliography of the NBS Electromagnetic Fields Division Publications**, NBSIR 85-3040 (February 1986).

This bibliography lists publications of the National Bureau of Standards' Electromagnetic Fields Division for the period from January 1984 through September 1985, with selected earlier publications from the Division's predecessor organizations.
[Contact: (303) 497-3132]

Sorrells, J.R., Palla, J.C., and Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NBS Electrosystems Division's Publications**, NBS List of Publications 94 (January 1986).

This bibliography lists the publications of the Electrosystems Division, Center for Electronics and Electrical Engineering, NBS, and of its predecessor sections for the period January 1968 through December 1985. A brief description of the Division's technical program is given in the introduction.
[Contact: (301) 975-2413]

Kline, K.E., and DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications**, NBSIR 86-3048 (June 1986).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NBS in the period from January 1970 through December 1985. A few earlier references that are directly related to the present work of the Division are included.
[Contact: (303) 497-3678]

Walters, E.J., **Semiconductor Measurement Technology; List of Publications -- 1962-1984**, NBS List of Publications 72 (March 1985).

This list of publications contains reports of work performed at the National Bureau of Standards in the field of Semiconductor Measurement Technology in the period from 1962 through December 1984).
[Contact: (301) 975-2050]

RECENTLY ISSUED STANDARD REFERENCE MATERIALS

The first practical superconducting standard reference material (SRM) has been released by the Electromagnetic Technology Division to the NBS Office of Standard Reference Materials for sale to the public. The certified parameter of SRM 1457, Superconducting Critical Current -- NbTi Wire, is critical current at magnetic fields of 2, 4, 6, and 8 tesla at a temperature of 4.2 K and an electric field criterion of 0.2 μV/cm. Information is given to permit the user to determine critical current for temperatures in the range 3.90 to 4.24 K and electric field criteria from 0.05 to 0.2 μV/cm.

SRM 1457 consists of a 2.2-m length of a multifilimentary, niobium-titanium, copper-stabilized wire, wound in a single layer on a spool having a core diameter of 8.7 cm. The wire is evaluated for 34 parameters relating to current, voltage, magnetic field, temperature, strain, and physical specimen characteristics.

In conjunction with ASTM Standard Test Method B714-82, D-C Critical Current of Composite Superconductors, the new SRM is intended to provide means for calibrating apparatus used to measure key parameters of superconductor products and thus should be useful to buyers and sellers of superconductors, users of superconducting equipment, and researchers in superconducting technology.

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10. SUPPLEMENTARY NOTES

All technical information included in this document has been previously approved for publication.

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This is the fourteenth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the first quarter of calendar year 1986. Abstracts are provided by technical area for both published papers and papers approved by NBS for publication.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

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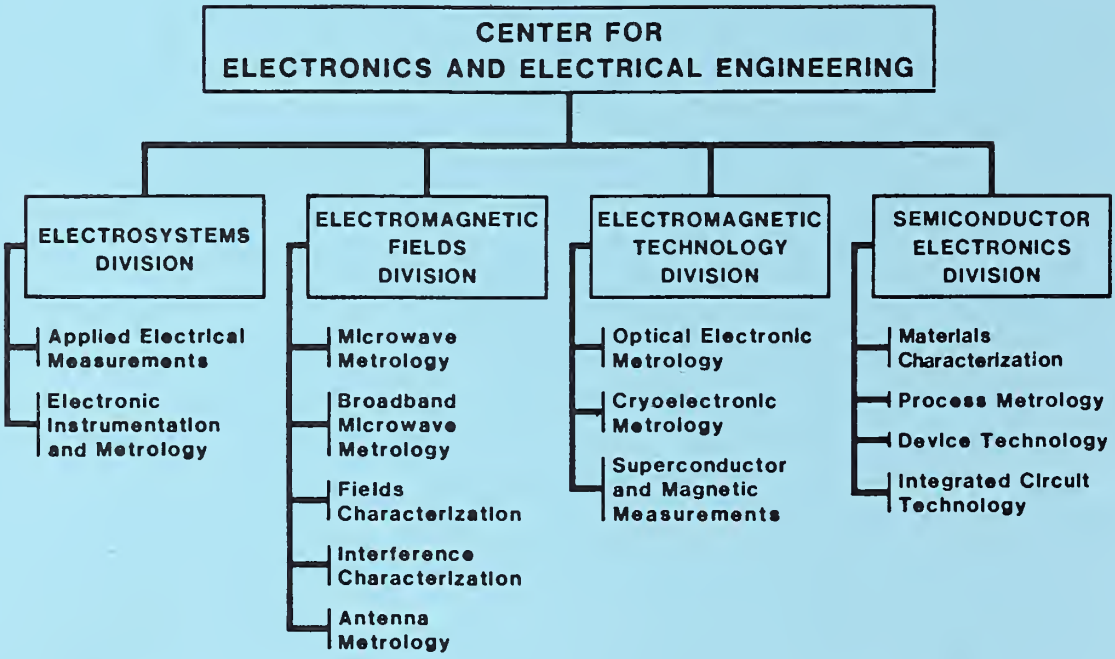

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